Use of Signal and Ambient Noise Coherence to Optimize Sonar System Performance

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Award Number: N00014-00-D-0119
http://www.onr.navy.mil/sci_tech/ocean/322_processes/prog_po.htm

LONG-TERM GOALS

Acoustic signal transmissions in littoral regions can have as much as 15 to 20 dB variability due to spatial and temporal effects [1]. Recent studies have shown that the ambient noise levels in the littoral also exhibit high variability that may be correlated to the littoral environment. Since both signal and noise variability have a direct impact on sonar system performance, an initial goal of this research is to relate the fluctuations in signal and noise, and their correlations to the relevant oceanographic features such as internal solitary waves and/or tides, shelf-break fronts, internal surface ducting, etc. An additional goal of is to develop simple rules-of-thumb to provide the sonar operator with the ability to exploit the oceanographic features (that lead to changes in sonar system signal and noise levels) and thereby optimize the overall system performance.

OBJECTIVES

The objectives of this research are to identify important oceanographic features which influence the signal and noise levels and their correlations. Our initial objective will be to study the ONR PRIMER experiment data conducted during the summer of 1996. This experiment has several advantages, including a dense set of oceanographic measurements and vertical line receiving arrays. Future objectives include the analysis of SHAREM data collected in the Yellow Sea, Sea of Japan and East China Sea.

APPROACH

Our technical approach is to examine the signal and ambient noise level characteristics measured during the PRIMER experiment and determine the appropriate correlations over time. To assist in this analysis we have begun to process these levels using digital filtering and FFT techniques. These analyses quantify relavent frequencies of the signal and noise level fluctuations and help identify the dominant physical oceanographic phenomena. We also plan to use cross correlation and coherent output power spectrum calculations to determine when and if the signal and noise level variations are related and/or coherent. For datasets such as the PRIMER experiment, in which data are measured with a vertical receiving array, we also plan to use vertical beamforming and/or modal decomposition so that the channel response can be selectively analyzed. The principle investigator, Mr. Philip Abbot is acting as technical director for this work, with most of the technical effort conducted at OASIS, Inc.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
30 SEP 2002

2. REPORT TYPE

3. DATES COVERED
00-00-2002 to 00-00-2002

4. TITLE AND SUBTITLE
Use of Signal and Ambient Noise Coherence to Optimize Sonar System Performance

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ocean Acoustical Services and Instrumentation Systems, Inc.,,5 Militia Drive,,Lexington,,MA, 02421

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Acoustic signal transmissions in littoral regions can have as much as 15 to 20 dB variability due to spatial and temporal effects [1]. Recent studies have shown that the ambient noise levels in the littoral also exhibit high variability that may be correlated to the littoral environment. Since both signal and noise variability have a direct impact on sonar system performance, an initial goal of this research is to relate the fluctuations in signal and noise, and their correlations to the relevant oceanographic features such as internal solitary waves and/or tides, shelf-break fronts, internal surface ducting, etc. An additional goal of is to develop simple rules-of-thumb to provide the sonar operator with the ability to exploit the oceanographic features (that lead to changes in sonar system signal and noise levels) and thereby optimize the overall system performance.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

by Dr. Charles Gedney and Mr. Christopher Emerson. Dr. Louis Goodman of the University of Massachusetts Dartmouth is a consultant on the project.

WORK COMPLETED

Work on this project commenced in the summer of 2002, thus the results presented here should be considered preliminary. The effort so far has been to analyze the PRIMER experimental data collected in the summer of 1996 at the shelf-break of the Middle Atlantic Bight south of New England (conducted under ONR sponsorship). We have obtained the acoustic measurements taken at the northwest vertical line array from Dr. C.S. Chiu at the Naval Postgraduate School. These data were transmitted from a 400 Hz (100 Hz bandwidth) source located 42 km to the south in the deeper water. Five second signals were transmitted continuously from the source during the entire 10 day period of the experiment and the received signals and ambient noise were processed using a matched filter that provided a pulse compression gain of about 27 dB.

The peak match filter output was determined for each transmission signal along with an average of the matched filter output noise measured between signal peaks. The variations in these signal and noise levels were then analyzed over the 10 day experiment. Semidiurnal tidal frequencies were strongly present in the signal levels due to the internal tide. Fluctuations were also observed at other frequencies that may be related to other oceanographic processes such as high frequency internal waves and solitons. Comparisons of the signal and noise levels showed that, at certain times, the fluctuations in the two levels seemed to be closely related, while at other times, they did not seem to be related. We have computed spectra of the signal and noise levels that show the strong semidiurnal frequency components along with the other, higher frequency components.

The signal and noise levels measured during the experiment have also been low-pass filtered to isolate the level variations which occur with periods larger than 2 hours (including the strong semidiurnal tidal period). The filtered signal and noise levels were then windowed and cross correlated to determine when these variations were highly correlated and when the were uncorrelated. Our results indicate that this correlation is high approximately every 8 hours. These preliminary findings are discussed further in the next section.

RESULTS

The matched filter output received at the hydrophone located 30.5m deep is shown in figure 1 for a typical transmission pulse. This figure clearly shows that both signal and ambient noise information can be obtained from the matched filter outputs. The peak signal level for this case is about 85 dB re 1μPa and arrives at about 28 seconds (the source to receiver time delay over a range of about 42 km). The signal then decays into the noise, which has peaks of about 70 to 75 dB re 1μPa. The overall peak of this output (85 dB) is recorded as the signal level, while the average level measured at time delays greater than 29 seconds (about 65 dB) is recorded as the corresponding ambient noise level. This process is then repeated for each pulse over the entire 10 day experiment.

In figure 2, the signal and noise levels are plotted versus the time at which the signal was received. This figure shows that both the signal and noise levels have a high degree of variability (15 to 20 dB) and the fluctuations at the semidiurnal and higher frequencies can also be seen in the figure. By comparing the signal and noise variations is this figure, we can begin to see some similarities in their

structure. However, it is the ratio of these two levels (the SNR) that affects sonar performance and our goal is to determine what oceanographic processes are controlling the variations.

To start our analysis of the correlation between the signal and noise level variations, we have decided to first subtract the overall (10 day) mean level of the variations and then to low-pass filter them to remove all variations having a period shorter than 2 hours. This removes all of the high frequency fluctuations and allows the analysis to focus only on the low frequencies (including the strong semidiurnal tidal cycles). The resulting variations were then windowed into short 4.3 hour segments and the correlation coefficients between the signal and noise windows were computed. These results are shown in figure 3 as a function of the starting time of the window. In this figure, a correlation coefficient of +1 means that, for periods longer than 2 hours, the windowed signal and noise levels are perfectly correlated. When the coefficient is 0, the windows are uncorrelated and at -1 the windows are correlated, but 180 degrees out of phase. From the results in the figure we have learned that the signal and noise windows are highly correlated about every 8 hours (3 times per day, as highlighted in the figure). These highly correlated windows are followed by windows where the correlation is relatively low and sometimes negative. Our current work is focused on learning more about the signal and noise correlations and what oceanographic processes are involved. We are also investigating the possible sources of the noise, including the position of local ships and how they may be affecting the measured ambient noise level.

Our future plans include similar investigations of the signal and noise levels measured in other datasets such as the SHAREM exercises conducted in the Yellow Sea, the Sea of Japan and the East China Sea. However, for these studies, new issues will arise such as the influence of the source and receiver positions, signal type (frequency, bandwidth, and pulse width), and the source and location of the ambient noise (shipping, sea surface, etc.), as well as the oceanography (sea surface conditions, internal waves and tides, fronts, surface ducting, etc.) and bottom conditions. These new influences will be investigated so that the final project conclusions will be more widely applicable.

IMPACT/APPLICATIONS

Clearly, variations in signal and noise levels directly affect the performance of sonar systems. By investigating these variations and how they are affected by the oceanography, we hope to develop simple rules-of-thumb that can be used by sonar system operators to optimize their systems' performance. If the signal and noise level variations can be predicted, the system operators may be able to plan and execute their operations with higher effectiveness and efficiency.

TRANSITIONS

(None)

RELATED PROJECTS

The Capturing Uncertainty DRI, which is currently being sponsored by ONR code 32 (Ellen Livingston), is closely related to the work reported here. Under the Uncertainty DRI, the work has been to enhance the understanding of the uncertainty in the ocean environment and to characterize its impact on tactical system performance through data analysis, modeling and sensitivity studies. These projects are closely related and some of the data and processing algorithms are shared.

REFERENCES

Abbot, P.A., Gedney, C.J., Dyer, I., and Chiu, C.S., "Ambient Noise And Signal Uncertainties During The Summer Shelfbreak PRIMER Exercise," Presented at the Impact of Environmental Variability on Acoustic Predictions and Sonar Performance, 16-20 September 2002, Lerici, La Spezia, Italy.

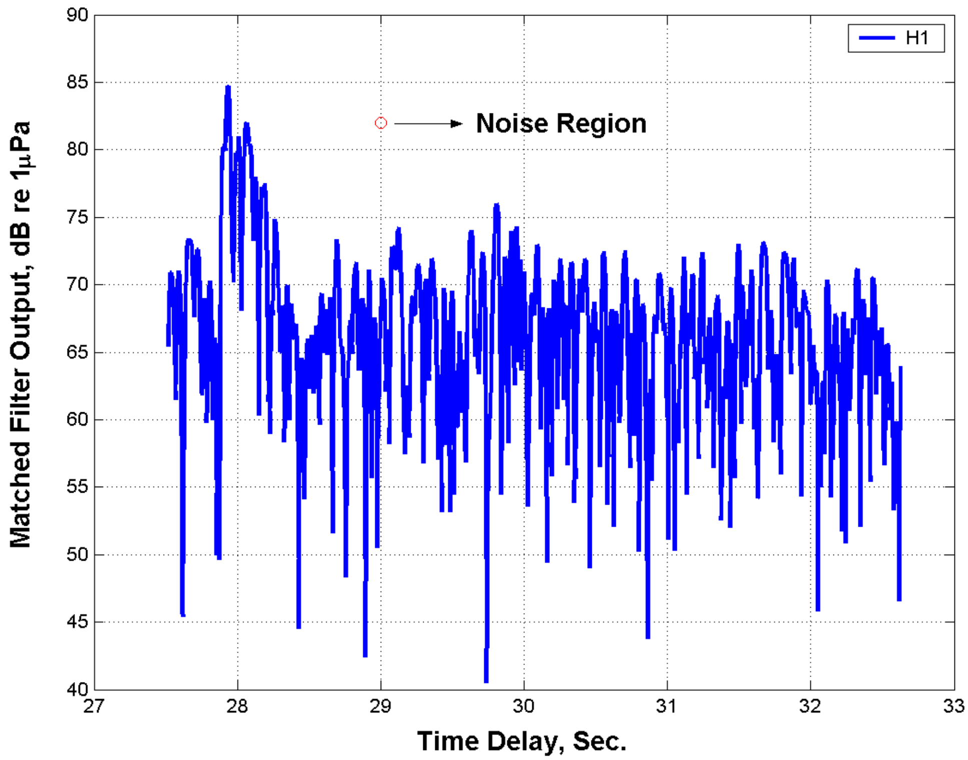

Figure 1. Typical matched filter output for a single 5.11 second transmission pulse, 30.5 m hydrophone depth.
[graph: matched filter output peaks at 85 dB re 1μPa at a 28 second time delay and decays to the ambient noise level of 50 to 75 dB re 1μPa at time delays between 28.5 and 32.5 seconds]

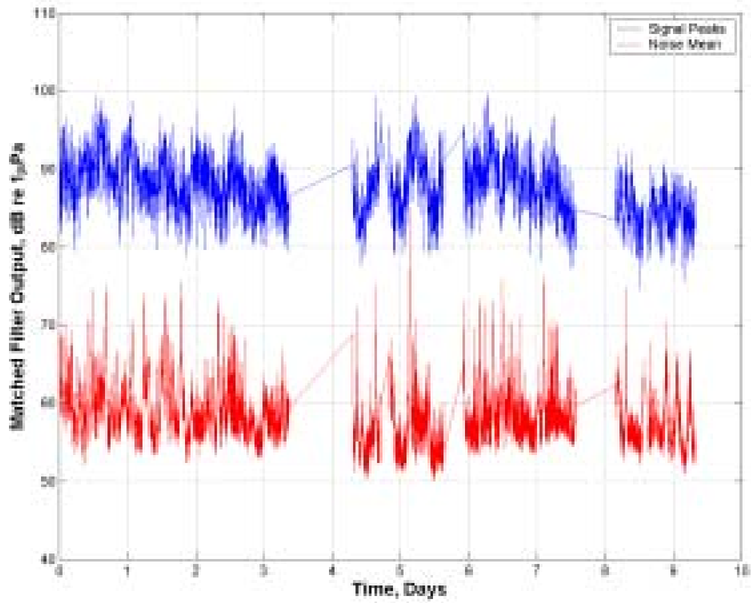

Figure 2. Signal and ambient noise levels measured throughout the 10 day PRIMER exercise, 30.5 m hydrophone depth.
[graph: peak signal levels vary from about 80 to 100 dB re 1μPa and ambient noise levels vary from about 50 to 70 dB re 1μPa over the 10 day PRIMER exercise]

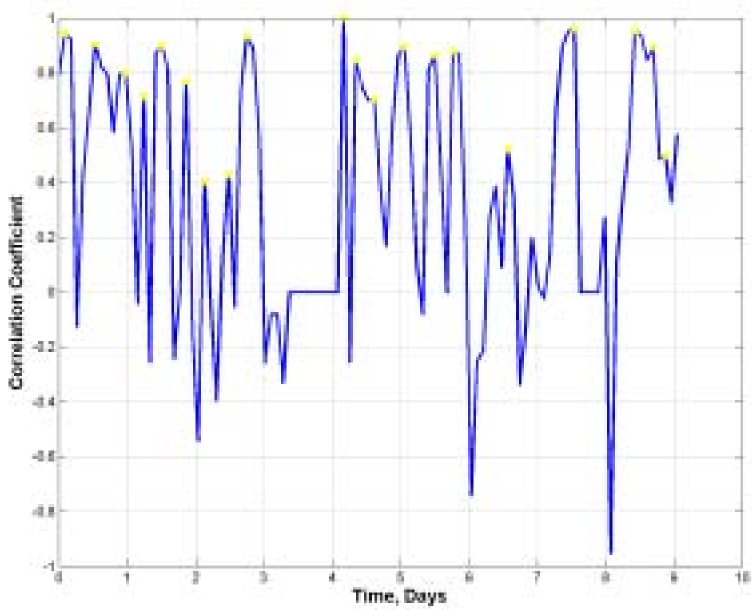

Figure 3. Correlation coefficient between signal and noise levels, low-pass filtered at 2 hrs, 4.3 hr analysis windows, 30.5 m hydrophone depth (highest correlation peaks are highlighted).
[graph: correlation coefficient peaks range from 0.8 to 1.0 approximately 3 times per day, between peaks coefficient minima range from about 0.2 to -1.0]